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Naturalistic Assessment of the Learner License Period

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Abstract

The purpose of this study was to describe the characteristics and progression of practice driving during the learner license period in a sample of teenagers. During the first and last 10 hours of practice driving, we examined (1) the amount, variety and complexity of conditions of practice; (2) the nature of parental instruction; and (3) errors that teens made while driving. Data were collected from 90 teens and 131 parents living in Virginia, USA, using in-vehicle cameras, audio recorders, GPS and trip recorders. Based on data collected from the instrumented vehicles, teens practiced for 46.6 hours on average, slightly higher than the GDL requirement for their jurisdiction, though half did not complete the required 45 hours of practice and only 17% completed the required 15 hours of night time driving. Exposure to diverse roadways increased over the practice driving period, which averaged 10.6 months. Most driving instruction occurred in reaction to specific driving situations, such as navigating and identifying hazards, and could be characterized as co-driving. Higher order instruction, which relates to the tactics or strategies for safe driving, was less frequent, but remained stable through the practice driving period. Instruction of all forms was more likely following an elevated gravitational force (g-force) event. Errors decreased over time, suggesting improvements in manual and judgment skills, but engagement in potentially distracting secondary tasks increased (when an adult was in the vehicle). A small percentage of trips occurred with no passenger in the front seat, and the g-force rate during these trips was almost 5 times higher than trips with an adult front-seat passenger. Taken collectively, these findings indicate (1) most teens got at least the required amount of supervised practice, but some did not; (2) instruction was mainly reactive and included some higher order instruction; (3) teens driving skills improved despite increased exposure to complex driving conditions, but secondary tasks also increased. Opportunities remained for improving the quality and variability in supervision and enhancing the development of skills during the lengthy period of practice.

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1. Introduction

The age when teenagers begin to drive corresponds to a period of particular vulnerability to motor vehicle crash injury. Graduated driver licensing (GDL) seeks to reduce the risks facing novice teenage drivers by phasing in their exposure to increasingly demanding environments (Johnson and Jones 2011). GDL requires progression through a learner license stage, where driving occurs only under adult supervision (typically a parent), to a provisional stage where teens can drive independently, with limited exposure to risky driving environments (e.g., late night driving, driving with teenage passengers; electronic secondary tasks), and finally to full independent licensure.

Learning to drive involves psychological, sociological, perceptual and motor processes. Learning theory provides insight into how novices learn, and while there are many competing theoretical frameworks, the classic conceptualization by Fitts and Posner indicates that learning occurs in three overlapping stages described as cognitive, associative and autonomous (Fitts and Posner 1967). The cognitive stage is typified by the development of explicit knowledge, which is defined as knowing what to do and how to do it under simple conditions. Associative learning focuses on the details, sequence and application of explicit knowledge under varying and complex conditions. The autonomous stage, which can occur only after substantial practice and experience, represents the internalization of associative learning, such that learners respond effortlessly, without consciously thinking about their behavior (Simons-Morton and Ehsani 2016).

Research on the development of expertise indicates that learning is a gradual process that occurs through extensive practice (Ericsson, Charness et al. 2006). A drivers' ability to identify and manage risks, and drive safely is therefore likely to increase as they accumulate experience (Elvik 2006). To encourage practice, many countries requires teens to complete a certain number of hours (for example, 50 hours in the majority of US states) during the learner stage of GDL. When practice occurs in a variety of increasingly demanding conditions, and is combined with feedback from parent supervisors, improvements in driving performance are most likely to be achieved (Ericsson, Krampe et al. 1993). Therefore, the amount of experience that a learner accumulates, the variety of conditions in which their practice occurs, and the nature of parental instruction they receive can be considered as the building blocks of the learner period.

Despite the fact that an extended learner period has been widely adopted in the U.S. and in several other countries as part of GDL, surprisingly little is known about the characteristics and progression of practice, and what is actually learned during the learner license stage. Research about how much teens actually practice is sparse and has relied mainly on self-reported measures (Waller, Olk et al. 2000, Williams, Nelson et al. 2002, McCartt, Hellinga et al. 2007, Scott-Parker, Bates et al. 2011, Jacobsohn, García-España et al. 2012, Bates, Watson et al. 2014). Self-reported accounts about practice driving may not be entirely accurate, given the fallibility of memory (Staplin, Gish et al. 2008), so objective data are needed about the number of hours teens practice. Further, Mirman and colleagues argue that a single, crude measure of supervision amount (either as hours of distance driven) does not account for practice diversity or instructional quality (Mirman, Albert et al. 2014).

Studies measuring practice diversity are rare, and have relied self-reported assessment of practice in different driving environments (Mirman, Lee et al. 2012, Mirman, Albert et al. 2014). Currently, the extent to which practice is repetitive, occurring on the same types of roads during the same time of day, or provides exposure to a variety of driving conditions is unknown. It seems plausible that the first hours of practice may be devoted to learning basic vehicle control (Hall and West 1996), and from then onwards, novices would be expected gradually to be introduced to increasingly challenging driving conditions. However, in a rare naturalistic driving study, Goodwin and Foss found practice driving was characterized mainly by routine driving trips on familiar roads, occurring in minimally challenging environments (Goodwin, Margolis et al. 2010). Basically, parents seemed focused on keeping their teens safe while they accumulated minimally challenging experience. Given the paucity of research on the topic, the need for objective measures of progression and driving diversity are needed to capture the characteristics and context of practice.

In addition to the amount and conditions of practice driving, the quality of driving instruction provided by parents during the learner period merits attention (Tronsmoen 2011, Mirman and Kay 2012, Scott-Parker, Senserrick et al. 2014, Ehsani, Simons-Morton et al. 2015). Survey studies from the U.S. and Norway found that parents tended to emphasize basic concepts, such as vehicle handling and control, and placed little emphasis on higher level skills, such hazard anticipation (Tronsmoen 2011, Mirman and Kay 2012). In their naturalistic study of parents supervising their teen drivers, Goodwin and Foss also found that instruction tended to focus on basic concepts, rather than on higher order skills such as managing a safe gap between vehicles (Goodwin, Foss et al. 2014). However, this study lacked the capacity to record continuously and could not assess routine driving given the relatively small sample of observations. Therefore, the extent to which instruction varied according to driving conditions, individual characteristics, or changes over time, has not been previously described.

Novices drivers frequently make mistakes (Curry, Hafetz et al. 2011), and provided these are not catastrophic, driving errors may provide useful opportunities for feedback as well as being an objective measure of learning. As skills and confidence improve, learner drivers' are more likely to accept greater challenges, experience more demands and possibly make different mistakes. To identify whether learners are advancing in their skills, objective measures of driving errors and the situations in which they occur are needed. On-road assessments developed by licensing authorities and for experimental studies (Hagge 1994, Mirman, Curry et al. 2014) have developed protocols for the measurement of driving errors in one-off assessments, but previous research has not measured errors while learning to drive as novices gain experience over time.

A better understanding of the amount, diversity and context of practice obtained by novice teen drivers, and the nature of the instruction provided by parents, is essential to improving the learner license period. Measurement of driving errors and the situations in which they occur would also inform how learning advances and skills acquired. Building on methodological approaches developed by Goodwin and Foss (Goodwin, Margolis et al. 2010, Goodwin, Foss et al. 2014), the goals of the current study were to describe the following characteristics of practice driving over time: (1) objectively measure the amount and conditions of practice driving; (2) the amount and type of instruction provided by parents; and (3) improvements in teen driving skills.

2. Materials and Methods

The vehicles of teenage drivers in southwestern Virginia, USA were instrumented with data acquisition systems (described in detail below) within three weeks of the teen obtaining a learner's permit. Participants were instructed to drive normally. In Virginia, teenage drivers below the age of 18 must hold a learner's permit at least nine months, and practice a minimum of 45 hours under the supervision of a licensed adult, of which 15 hours should occur at night (Virginia Department of Motor Vehicles 2016).

2.1. Participants and selection criteria

The study required the participation of teenage drivers and at least one of their parents. Recruitment was conducted in local newspapers and high schools in southwestern Virginia, USA. Teen participants were initially screened in a telephone interview for eligibility using the following inclusion criteria: (a) being between 15.5 and 16.1 years old; (b) holding a learner driver's license for no more than three weeks; (c) having at least 20/40 corrected vision; (d) having at least one parent willing and able to participate; (e) access to a vehicle expected to survive mechanically for at least 18 months; (f) residing within a one-hour drive of the research center or satellite location; and (g) holding liability insurance on the vehicle to be used in the study (required by state law). Parent participants were required to (1) have a valid U.S. driver's license, vehicle insurance, and proof of ownership (2) have a child who was eligible and willing to participate in the study and who was allowed by their parent to participate (3) have at least one of their vehicles equipped with instrumentation required for the study. Participants were excluded based on the prescreen telephone interview or these reasons: (a) diagnosis of attention deficit disorder (ADD) or attention deficit hyperactivity disorder (ADHD); (b) an identical twin (which would make it difficult to distinguish participants during coding); and (c) the need to enter restricted areas (i.e., that do not allow cameras for security reasons). Participant recruitment was stratified to have a similar number of male and female teenage drivers. A total of 298 individuals responded to recruitment efforts, of which 90 fulfilled the eligibility criteria and were enrolled in the study. In 41 families, a second parent consented to having their driving data collected but did not complete any other elements of the study. Data were collected from January 2011 to August 2014.

2.2. Consent and compensation

Three consent forms were required for the study: parental consent and teenagers assent for their participation, and an adult consent form for parent participation. Teenager assent was obtained separately from the parent to ensure their participation was voluntary, and free of parental coercion. Teenage participants received $800 for completing the study, paid to them in installments as they completed key milestones. The protocol was approved by the Virginia Tech Institutional Review Board for the Protection of Human Subjects.

2.3. Instrumentation

Instrumentation was installed in the vehicle in which most practice driving would occur. The data acquisition system included a computer that received and stored continuous data from accelerometers, a global positioning system (GPS) that calculated vehicle position, and cameras. Video images monitored the driver's face, the dashboard, and areas reachable by the driver's hands, as well as the forward and rearward roadway. A separate camera was used to take still photo images of the interior cabin of the vehicle every 5 minutes of a trip. A microphone recorded in-vehicle conversation and driving instruction. Additional detail about the properties of the data acquisition are described by Dingus and colleagues (Dingus, Guo et al. 2016).

2.4. Data coding

Data coding was conducted on each trip file, including video and audio data generated during practice driving, and also on elevated gravitational force events, and crashes and near-crashes.

2.4.1. Trip coding—A trip was defined as beginning when the vehicle ignition was turned on and ending when the ignition was turned off. Trip duration was calculated using the timestamp corresponding to ignition on and ignition off, regardless of vehicle movement. GPS recorded the movement of the vehicle and the distance traveled (miles) in each trip. Sunrise and sunset times were obtained from timeanddate.com (Time and Date AS 2015). Precipitation data were obtained were obtained from the National Oceanic and Atmospheric Administration's historical data for Roanoke airport (National Oceanic and Atmospheric Administration 2015). These data were merged with trip level information to estimate ambient light and road surface conditions. If a trip began before sunset it was considered a daytime trip. If a trip began when there was no precipitation, road conditions were coded as being dry.

2.5. Video and Audio Data

2.5.1. Sampling and Coding Protocol—Video and audio data were simultaneously and continuously recorded throughout the entire learner period. A coding protocol was developed to capture the nature and intensity of driving instruction, driving errors that occurred during practice, and the road types that learners encountered, using both video and audio data (Ehsani, Simons-Morton et al. 2015).

To assess the progression of practice over time, we sampled the data as follows: (a) random sample of a 30-second driving segment from each consecutive five-minute period of driving during the first and last ten hours of practice; and (b) for trip durations not divisible by 5 minutes, the last minutes of the trip were not sampled (e.g. if a trip was 24 minutes long, the last 4 minutes would not be sampled). Each participant generated approximately 120 segments for each ten-hour period of practice driving, and both audio and video data were coded for each segment. If the audio data was not clear or audible to the coders, the segment was excluded from the sample. If the randomly selected clip began in the middle of the conversation, the coder was instructed to review the 30 seconds of sampled audio and provide an assessment based upon that 30 seconds of time. If needed, coders could listen to the prior 30 seconds to gain context but needed to base the responses to the coding exclusively on the 30-second segment.

2.5.2. Audio data—Audio data were collected while the ignition was on and would include conversations while parked with ignition on. For each recorded segment, the conversation between parents and teens was coded as (1) related to driving; (2) not related to driving; (3) related to both driving and non-driving; or (4) no conversation present. Clips with driving-related conversations were further coded according to the presence of functional and higher order instruction. Functional driving instruction was defined as instruction that relates to the present time or immediate future and related to specific events that are occurring during the drive itself. Higher order driving instruction was instruction that could be extrapolated to a future driving situation that conveys general principles of driving related to potential events that occur (Ehsani, Simons-Morton et al. 2015). The topics of the instruction included vehicle handling, remarking on driving behavior, navigation, warning/detecting hazards, rules of the road, and questions about driving. Functional and higher order instruction could, at times, overlap. The coding protocol included instances where both functional and higher order instruction were simultaneously present and constantly interacting. This category was called “both functional and higher order instruction”. In such cases, it was coded as a separate instance of functional and higher order instruction.

2.5.3. Video data—Video data were collected simultaneously with the audio data and coded for the presence of passengers, road type and driving errors. Fourteen driving errors, and the roadway type where the error occurred were coded, and allocated to one of three categories: (1) recognition errors; (2) decision errors; and (3) performance errors; these categories were based on the classification system developed by the National Highway Transportation Safety Administration (Treat, Tumbas et al. 1979) and adapted by Curry and colleagues (Curry, Hafetz et al. 2011). High-risk secondary tasks, which involved highly demanding visual-manual tasks, were also recorded (Klauer, Guo et al. 2014).

2.5.4. Data coding inter and intra-rater reliability—Five trained coders categorized the topics and nature of driving instruction, driving errors, secondary tasks and the road types that learners encountered during the learner stage of driving. Coders were trained using a documented coding protocol with the coding manager reviewing 100% of their work until the trainee coder achieved a high degree of accuracy. Following the initial training, an expert coder would spot check the coders and conduct intra-rater testing of video segments. A separate inter-rater test was conducted, consisting of each rater coding 30 video segments on 80 variables collected in the protocol. An inter-rater test indicated 86% average accuracy between the coders and an expert coder.

2.6. Accelerometer data

2.6.1: Elevated G-force Events—An accelerometer was encased in a special bracket that allowed for the continuous measurement of gravitational forces (g-forces) along X, Y and Z axes for each trip. Using the accelerometer data, elevated g-forces (events) during the learner permit period were identified. Audio and video data corresponding to the 30 seconds following the event were evaluated, consistent with the methodology of video and audio coding developed by Goodwin et al. (12) described earlier. Five hundred video segments were sampled from highly elevated g-force events during the practice driving period.

The types of events were counted at specific gravitational levels: (1) rapid starts > 0.35g (2) hard stops ≤ 0.45g (3) hard left turns ≤ −0.5g (4) hard right turns ≥ 0.5g and a (4) yaw rate oscillating +/− 6 degrees/second. Yaw is the measure of correction after a swerve and is calculated as the delta-V (change in velocity) between an initial turn and the correction or swerve. These thresholds were selected as they have previously been shown to predict crashes and near-crashes in a similar sample of novice teenage drivers (Simons-Morton, Zhang et al. 2012). On a test track, investigators and staff rode as passengers in an instrumented vehicle driven by a technician following a protocol in which he created many elevated g-force events, some lower than the target thresholds and some at or higher, and recorded subjective reactions to the events. Those experiencing events at or above the threshold levels described above reported that it made them uncomfortable and concerned about the vehicle going out of control. Passengers experience lateral events at these levels as being thrown uncomfortably to the side; acceleration events throw the passenger uncomfortably into the seat belt or back into the seat.

2.6.2. Crashes and Near-crashes—Trained data coders also reviewed the video and the corresponding to excessive g-force events allowing the identification of crashes and near-crashes. Once a potential event was identified, data coders reviewed the corresponding video and classified the event as either a crash or as a near-crash, defined as follows: A crash was any contact with an object, either moving or fixed, at any speed in which kinetic energy is measurably transferred or dissipated. Includes other vehicles, roadside barriers, objects on or off of the roadway, pedestrians, cyclists, or animals. A near-crash was any circumstance that requires a rapid, evasive maneuver by the subject vehicle, or any other vehicle, pedestrian, cyclist, or animal to avoid a crash. A rapid, evasive maneuver is defined as steering, braking, or accelerating.

2.7. Roadway diversity

The roadway types that learner drivers encountered were measured using video from the first and last ten hours of practice driving was used to code. Five roadway types were captured, including parking lots, residential or rural roads, suburban or commercial roads, urban or commercial roads, and highways. A measure of roadway diversity was developed using the formula $\frac{\sum_{n=1}^{v}(r_n) - v}{v}$ where r = # roadway types; rn = # roadway types in nth video clip; and v = # video clips. Diversity could range from zero to four; higher values reflecting driving on a greater variety of road types during an observed clip.

2.8. Analysis

We assessed and conducted comparisons of the amount of driving instruction, driving errors, and secondary task engagement between the first and last ten hours of practice. We chose this approach, rather than simply randomly sampling over the period of practice to better capture early and late practice period given the wide range among drivers in the length of practice period and the amounts they drove over time. In the first ten hours of driving 9,823 clips were generated by 90 teens and their parents. Due to participant withdrawal and limited driving by some participants, the last ten hours of driving generated 8,523 clips by 79 teens and their parents. We also compared driving instruction during highly elevated g-force events to normal driving used the 500 elevated g-force events across the learner permit period, generated by 78 participants. The combined number of segments from the first and last ten hours of driving (N = 18,346) was used as the sample of normal or routine driving. The likelihood of conversation and driving instruction during routine driving (baselines) and elevated g-force events was calculated using mixed models, where data from participants who generated both routine driving and elevated g-force events are used.

Each teen and parent generated multiple observations. To account for multiple observations for each participant, generalized linear mixed models with a random effect, with a logit link were used to estimate the likelihood of driving instruction, errors and secondary task engagement during the first and last ten hours of driving. To eliminate the potential for sampling bias, the mixed-model only used data from participants for whom observations were collected from both the first and last ten hours of driving. The same technique was used to compare elevated g-force events and routine driving. ANOVA and a post-hoc Tukey's test were used to compare the amount of instruction provided by mothers and fathers to daughters and sons. Analyses were conducted in SAS 9.4.

3. Results

3.1. Sample Characteristics

At recruitment, the teenage sample consisted of 49 females and 41 males with an average age of 15.6 years (SD 0.2). Thirteen participants' driving data was collected from two vehicles, as instrumentation was fitted to a second household vehicle driven by the teenager, and a single participant provided data from three vehicles. The average age for all vehicles was 10.1 years (SD 4.3). Mothers made up almost two-thirds (N=57, 63.3%) of the primary adult participants in the study. Approximately half the sample (46.6%) reported a household income of over $100,000. Of the 90 teen drivers recruited, three teens remained on their learner permit for the duration of the study. Four teens withdrew from the study due to vehicle-related issues (teen or parent involved in a crash and did not want to re-instrument the new vehicle, sold the instrumented car, or moved out of state). Hence, eighty-three completed the learner permit stage, advanced to independent licensure, and were included in the analyses. All available data were used in the analyses, and no participant data was excluded.

3.2. Learner License Duration, Practice Driving Amount, and Driving Conditions

Participants held their learner permit for an average of 10.64 months (SD = 2.83). Fifty-two participants (62.65%) held their learner permit for less than or equal to 10 months. Twenty-one months was the longest duration a participant held a learner's permit before licensure or timing out of the study (see Table 1). Based on data from the instrumented vehicles, forty-one participants (45.6%) completed at least 45 hours of supervised practice driving, the minimum required amount in the State of Virginia. Learner drivers did the majority of their driving during daylight hours and in dry conditions. On average 36.6 hours (SD = 25.4) and 958.6 miles (SD = 701.8) were spent driving during daylight, compared to 10.1 hours (SD = 10.2) and 263.4 miles (SD = 300.4) at night and only fifteen participants (16.7%) completed the required 15 hours of night driving in the instrumented vehicles during the learner license. Teens were involved in 9 crashes and 13 near-crashes (CNCs) in the instrumented vehicles during the practice driving period, corresponding to a rate of 2.6 CNCs per 10,000 miles driven (SD = 5.5).

The average number of trips, miles and hours during the learner permit period are described in Table 1 and Figure 1. Participants drove a total of 18,686 trips, an average of 207.6 trips each. Per teen participant driving occurred on 88.9 days (SD = 45.6), for 1219.1 miles (SD = 920.2), and 46.6 hours (SD. 32.8), but with substantial variation – the bottom 25% obtained an average of 502.4 miles of practice while the top 25% obtained 1657.6 miles of practice, with similar variability for night, inclement weather, and other practice driving conditions. The average trip was 5.89 miles and 13.67 minutes. Teenagers drove an average of 315 miles in the first month and 441 miles in the last month of the learner period. There was a wide between-subjects range of exposure to driving, as shown by the standard error bars in Figure 2, but no change in the average trip length or monthly miles driven was observed across the learner license period. Significantly more miles were driven in dry weather, relative to wet weather. On average 41.5 hours (SD = 29.2) and 1092.9 miles (SD = 826.2) were spent driving in dry conditions, compared to 5.2 hours (SD = 4.2) and 127.5 miles (SD = 112.7) in wet conditions. Driving on diverse roadways significantly increased over time, with all participants encountering significantly more diverse roads in the final ten hours of practice (mean = 0.41, SD 0.18) compared to the first ten hours (mean = 0.32, SD 0.16)) (($p < .001$). There were no significant differences across all the measures of driving exposure (trips, miles, hours, days) according to individual characteristics of the participants, such as gender, age at recruitment, and the length of time they held their learner permit.

Passenger presence information was available for 12,345 trips or 60.5% of all trips occurring during the learner license period. An adult was the front seat passenger at the start of 10,244 these trips (82.8%), and a child or teen was the front seat passenger for 187 trips (1.5%). Passenger age could not be determined for 1,109 trips (9.0% of trips). Teens drove with no passenger in the front seat for 320 trips (2.6%). Trips with no front seat passenger had an elevated g-force event rate that 4.75 times higher, compared to when an adult was in the front seat ($p<.0001$).

3.2. Driving instruction during the first and last ten hours of practice

Instances of driving instruction observed during the first and last ten hours of practice driving are presented in Table 2. Conversation overall was greater during the first 10 hours than the last (49.9% vs. 31.2%; OR = 0.42, 95% CI = 0.39, 0.45). Functional instruction was the most frequently occurring form of supervision that parents provided during the learner permit stage. Functional instruction was highest during the first ten hours of practice driving, particularly related to vehicle handling and navigation and remained the primary form of instruction during the last ten hours of practice. The percentage of instruction dedicated to functional instruction declined significantly from 49.9% during the first 10-hours to 31.2%

during the last 10 hours. Higher order instruction by parents was stable throughout the practice driving period (13.3% vs. 12.5%; OR = 0.99, 95% CI = 0.90, 1.09), though the topics varied between the first and the last 10 hours and the variability in higher order instruction decreased in the final ten hours of driving. The amount of higher order instruction about navigation significantly increased (0.9% vs. 1.7%; OR = 1.92, 95% CI = 1.46, 2.53). The remaining topics decreased relative to the first ten hours of practice driving. Due to an overall decline in both functional instruction, the ratio of higher order instruction to functional instruction increased over time.

Gender-based differences in the amount and type of instruction were examined as a function of the gender of the driver and the supervisor. Differences between the instruction provided by mothers and father to their sons or daughters were not observed, with a single exception; over the course of the learner period, mothers provided greater higher-order instruction to sons than to daughters ($p < .05$). Teens who were older in age at the time they received their learner permit were marginally more likely to receive higher order instruction related to vehicle handling (OR = 1.10, 95% CI = 1.02, 1.12) and those who held their learner permit for longer than average were more likely to receive all forms of driving instruction (OR = 1.07, 95% CI = 1.02, 1.13). Specifically, they received more functional instruction related to vehicle handling (OR = 1.07, 95% CI = 1.02, 1.13) and a greater amount of higher order instruction related to hazard detection (OR = 1.06, 95% CI = 1.00, 1.12).

3.3. Driving Instruction during Routine Driving and Elevated G-force Events

Parent-teen communication following an elevated g-force event differed from the communication that occurred during routine driving (Table 3). Events were significantly more likely to be followed by conversation between the parent and the teen, compared to normal driving (OR = 1.63, 95% CI = 1.23, 2.15). Both functional and higher order instruction were more likely following an elevated g-force event, relative to what parents said during normal driving).

Functional instruction during elevated g-force events was more likely to be about immediate warnings or hazards (OR = 3.16), 95% CI = 2.47, 4.05), vehicle handling/operation (OR = 3.70, 95% CI = 3.03, 4.50), commenting on driving behavior (OR = 4.56, 95% CI = 3.69, 5.62), question about driving tasks (OR = 7.16, 95% CI = 4.01, 12.76), or related to the rules of the road (OR = 1.92, 95% CI = 1.38, 2.68). No significant differences were observed between functional instruction related to navigation following elevated g-force events and normal driving (OR = 1.19, 95% CI = 0.91, 1.55). The same patterns were observed for higher order instruction following elevated g-force events and routine driving.

We also considered how in-vehicle conversation and driving instruction following elevated g-force events changed over time. Of the 500 identified elevated g-force events, 129 occurred during the first ten hours of driving and 118 occurred during the final ten hours of driving (the others occurred during un-sampled road segments between the first and last 10 hours). A significant reduction in conversation was observed during events in the final ten hours of driving (OR = 0.56, 95% CI = 0.38, 0.93). There was also a trend towards less functional and higher order instruction following elevated g-force events during the final ten hours of driving (OR = 0.67, 95% CI = 0.41, 1.12 and OR = 0.73, 95% CI = 0.52, 1.03 respectively), although neither reached statistical significance.

3.4. Prevalence of Driving Errors and Secondary Tasks

Performance errors were the most common error type across the learner permit period (Table 4). A total of 1,243 performance errors, mostly related to lane management and improper vehicle operation, were observed across all participants during the first ten and last ten hours of driving. There was considerable variability among the participants in performance errors, demonstrated by the high standard deviations related to these errors. Decision errors, mostly related to speed management, occurred less frequently during the first and last ten hours of driving (N = 476) and declined rapidly as learner gained experience. Recognition errors were the least common (N = 124) during the leaner period, and were primarily due to inattention and distraction.

To determine changes in teens' driving error rate over time, we examined the prevalence of errors during the first ten hours of practice driving relative to the final ten hours (Table 4). Driving errors significantly decreased over time (13.4% vs. 8.8%; OR = 0.76, 95% CI = 0.68, 0.84). Performance errors related to vehicle management did not change (8.4% vs. 6.8%; OR = 1.10, 95% CI = 0.97, 1.25), primarily due to a significant increase in errors related to lane management (4.8% vs. 6.4%; OR = 1.72, 95% CI = 1.49, 1.98). Decision errors, which include speed management, gap acceptance errors and a failure to stop or yield, also decreased (3.5% vs. 1.4%; OR = 0.40, 95% CI = 0.32, 0.49). Recognition errors, which include failures to detect hazards and inattention, significantly decreased during the final ten hours of driving (0.9% vs. 0.4%; OR = 0.43, 95% CI = 0.29, 0.65). Driving errors decreased across all road types with a single exception on highways, reflecting the overall trend towards fewer errors occurring in the final ten hours of practice driving. A trend towards a significant increase in errors on highways was observed (9.8% vs. 9.5%; OR = 1.21, 95% CI = 0.99, 1.48).

Performance errors during the first ten hours of practice were positively correlated with functional instruction during the first ten hours of driving ($r = .39$, $p = .0001$), meaning the amount of instruction increased as the number of errors increased. No other associations between driving errors and instruction were observed. Teens who were older at the time they received their learner permit were marginally more likely to make driving errors related to improper turning (OR = 1.10, 95% CI = 1.02, 1.12), while those who held their learner permit longer than the average were less likely to make gap acceptance (OR = 0.65, 95% CI = 0.44, 0.94) or hazard detection errors (OR = 0.65, 95% CI = 0.44, 0.94). No differences in driving errors were observed between male or female participants. High-risk secondary tasks, including cell phone use, eating and reaching for objects, were twice as likely during the final ten hours of practice driving, compared to first ten hours (9.9% vs. 5.8%; OR = 1.90, 95% CI = 1.70, 2.14).

4. Discussion

The learner stage represents a unique period where novice drivers begin to develop the skills and judgment necessary to keep them safe during independent driving (Goodwin, Foss et al.

2014, Mirman, Albert et al. 2014, Peek-Asa, Cavanaugh et al. 2014). Like most complex motor tasks, driving skills develop through deliberative practice, under the guidance of someone who is more experienced (Starkes, Deakin et al. 2014). The purpose of this study was to describe the amount and conditions of practice, the nature of instruction, and the types of driving errors that occurred overall and during the first and last 10 hours of the learner license stage. We used continuous observation and intensive measurement throughout the course of the learner period, an approach that had not been previously employed to examine practice driving.

On average, we found that teens practiced steadily throughout the learner permit period and encountered increasingly diverse roadways. Parents' driving instruction was highest at the beginning of practice and tapered off as teens gained more experience. Instruction tended to be in response to what was occurring on the road and focused on the immediate demands of driving, with less attention to higher order principles and strategies for safety. Learners who were older when they received their permit and those who held their permit for longer were more likely to receive various types of driving instruction. For example, those who held their learner permit longer received greater instruction related to strategic aspects of hazard detection. This may reflect parents' perceptions of their need for additional instruction or teens' greater openness to instruction and potentially to delaying licensure. Driving errors decreased overall, but certain error types persisted and increased as teens advanced through the learner permit period, which may indicate increased driving demands. Those who were older when they received their learner permit committed more turning errors, while those who held their permit for longer committed fewer errors related to gap acceptance and hazard detection. Curiously, functional instruction and performance errors were positively correlated, which suggests that instruction is related to the development of driving skills, although not in the direction we would have anticipated. Possibly, instruction follows errors rather than precedes it, so parents provide more instruction to learners who make errors, which seems logical.

Based on data from the instrumented vehicles, teens practiced for an average of 46.5 hours; slightly higher than the GDL requirement of 45 hours in Virginia, USA. However, there was wide variability in the sample with some teens practicing only a few hours, while others practiced for hundreds of hours. Using the number of hours logged by the data recorders, more than half the sample drove less than 45 hours (which is the minimum requirement in jurisdiction where the study was conducted), and a small number of participants drove far more than the 45-hour requirement. One possible explanation for this variation is that some teens may have driven vehicles other than those instrumented for the study. Another explanation is that there is variation in how much teens actually practice, but that the 45-hour requirement might anchor parents and teens at a certain amount of practice. This is reflected in the clustering of practice driving occurring around the number of required hours. The majority of teens failed to practice for more than 15 hours at night in the instrumented vehicles, which is required as part of Virginia's GDL. Consistent with previous studies on crash risk during the learner stage (Mayhew, Simpson et al. 2003), the observed crash rate during practice driving was low, with no severe crashes occurring during the study period.

Driving on diverse roadways increased across the course of practice driving. Given that most of newly independently licensed teen drivers' exposure is to new and unfamiliar locations (Musicant and Benjamini 2012) it seems likely that experience on different road types would enhance novice driver learning. As the amount of practice driving in our sample did not increase over time, the observed increase in practice on diverse road types suggests that parent supervisors increased or allowed an increase in the complexity of driving over time. Teens living in areas where the driving environment is relatively homogenous may require additional practice guidance on where to gain supplemental experience beyond their locality, and mobile applications that include GPS tracking could be used to document how much of driving is occurring and where it is taking place.

Curiously, 2.6% of trips did not have an adult in the front seat, suggesting joy riding, and teens drove in a riskier way during these trips. In-vehicle cameras could not detect the presence of rear-seat passengers, but the characteristics of these trips appeared to be distinct from routine driving. The g-force event rate during these trips was almost 5 times higher compared to when an adult was a front seat passenger. The presence of an adult in the vehicle while the teen is driving is known to reduce the number of elevated g-force events (Simons-Morton, Ouimet et al. 2011), which suggests that these trips did not have an adult passenger present. Not having an adult present in the vehicle is illegal during the practice driving period. Further, engagement in potentially-distracting (and prohibited by GDL) secondary tasks, such as cell phone use, increased twofold over the course of practice driving while parents were in the vehicle. These violations of GDL requirements during the practice driving stage may suggest that restrictions on high risk behavior may not be taken seriously by teens and parents. Compliance with requirements during the independent driving stage may decline further (Goodwin and Foss 2004).

While parents engaged in supervision, it appears that much of the instruction they provided can be characterized as co-driving, typified by proximal remarks on navigation, vehicle handling, and anticipation of possible hazards. Early on, co-driving is useful and necessary, as teens need guidance to develop the basic skills of way-finding and vehicle handling. Encouragingly, co-driving and other types of instruction declined over time, which may reflect teens' greater driving skills, and a deliberate strategy on the part of parents to give or acquiescence to allow teens greater autonomy for making driving decisions. Although higher order instruction was less frequent, it remained steady throughout the learner period and the variability decreased in the final ten hours of driving. The overall proportion of instruction dedicated to higher-order topics increased over time; largely due to a relative decrease in overall instruction. A significant increase was observed in high-order navigation-related instruction. Navigation is a key element of everyday driving that requires the integration of a number of skills, such as planning, lane choice, and working memory (Maguire, Burgess et al. 1998). It appears that once basic vehicle handling skills had been mastered, some parents turned their attention to some extent to the practical aspects of driving, such as way-finding, rather than imparting safe-driving practices such as hazard detection. Low levels of higher order instruction have been reported by other studies (Mirman and Kay 2012, Goodwin, Foss et al. 2014), and research efforts are underway to assist parents to providing instruction that reflects the full breadth of their own safety judgments and experience. We found an overall reduction in driving errors over the course of practice driving, presumably the result of accumulated experience, coupled with instruction provided by parents. The exception was performance errors related to vehicle management, which remained steady. This persistence occurred despite increased exposure to more demanding driving environments in the latter stages of practice. Errors reduced on all road types, with the exception of highways, and may reflect greater exposure to these roads in the last ten hours of practice driving. During early practice, teens' errors were positively associated with the amount of functional instruction provided by parents. This suggests that driving instruction was more common in reaction to events than proactive and anticipatory, a findings that has been reported elsewhere (Goodwin, Foss et al. 2014). Events may serve as teachable moments, prompting direct and specific feedback about driving behaviors that require attention. Strategies to shift the emphasis of parental supervision towards proactive guidance may enhance the quality of the practice driving period. Further research is needed on the factors that might improve the amount and quality of practice, such as parental support (Mirman, Curry et al. 2014), parental modeling of driving behavior (Taubman – Ben-Ari 2010) and the pre-existing parent-teen dynamic (Laird 2014).

Limitations

The study population was a highly motivated, self-selected sample of novice drivers who had committed to the ongoing assessment of their driving behavior. They were generally from higher income households relative to the state average, and are likely to have had greater parental involvement in the process of learning to drive than the average teen in Virginia. During the study period, average household income in Virginia was $61,406 (U.S.Census Bureau 2013), whereas half of participants in this study came from reported a household income of over $100,000. As a result, the main findings of this study may not be fully generalizable to the population of parents and novice teen drivers. For example, the amount and type of instruction provided by parents in the general population is likely to be less than what was observed in this sample. It is possible that the observation of participants may have had some short-term effect on participant behavior. Previous naturalistic driving studies have reported an initial period of cautious driver behavior (Dingus, Klauer et al. 2006).

Any practice driving that occurred in non-instrumented vehicles was not included in our estimate of how much teens drove during the learner permit period. Therefore, it is possible that the measures of exposure are under-estimates of the amount of driving that took place. All study participants were required to complete the standard driver education course, which would have contributed to their learning and experience, apart from parent supervised practice. As this was a naturalistic observational study, all recruited teen participants were required to advance through Virginia's graduated driver licensing system, and instructed to drive as they normally would under the supervision of a licensed driver. Therefore, of course, participants could not be randomized to a supervision or non-supervision group to test the effect of supervised practice driving.

Conclusions

The findings that teens practiced steadily throughout the learner permit period and experienced increased road type diversity; driving instruction provided by parents was primarily in reaction to events and co-driving; higher order instruction was less frequent than functional instruction, but increased over time; and errors decreased over time suggesting manual and judgment skills improved with practice. Despite considerable variability, these findings are consistent with the following: (1) more than half the teens obtained the required amount of practice; though many did not and the majority did not complete the required 15 hours of driving at night (2) parent supervision and instruction was at least adequate, although it tended to be reactive, included less than desirable higher order instruction, and became lax with respect to teen driver secondary task engagement; and (3) errors declined over time even as driving complexity increased, suggesting improvement with practice and instruction; crash rates during practice driving were low and none were severe. Nonetheless, there was substantial variability in practice driving and opportunities remain for improving the quality and variability in supervision and enhancing the development of skills during the lengthy period of practice. Based on these findings, improvements in the amount and utility of supervised practice driving is likely to be achieved by focusing on the families that provide and obtain the least amount and least complex experience, fail to progress over time in the complexity of practice driving over time, and provide little instruction, particularly higher order instruction.

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Highlights

- Teens practiced for an average of 46.6 hours, but less than half (41 of 90 participants) completed the required the GDL requirement of 45 hours in Virginia, USA
- Exposure to diverse road types increased over the course of the practice driving period
- Parental instruction was primarily focused on the immediate demands of driving
- Driving errors decreased over time, suggesting that manual and judgment skills improved with practice
- 2.6% of trips did not have an adult in the front seat, and teens drove in a riskier way during these trips
- High risk secondary task engagement increased twofold over the course of practice driving

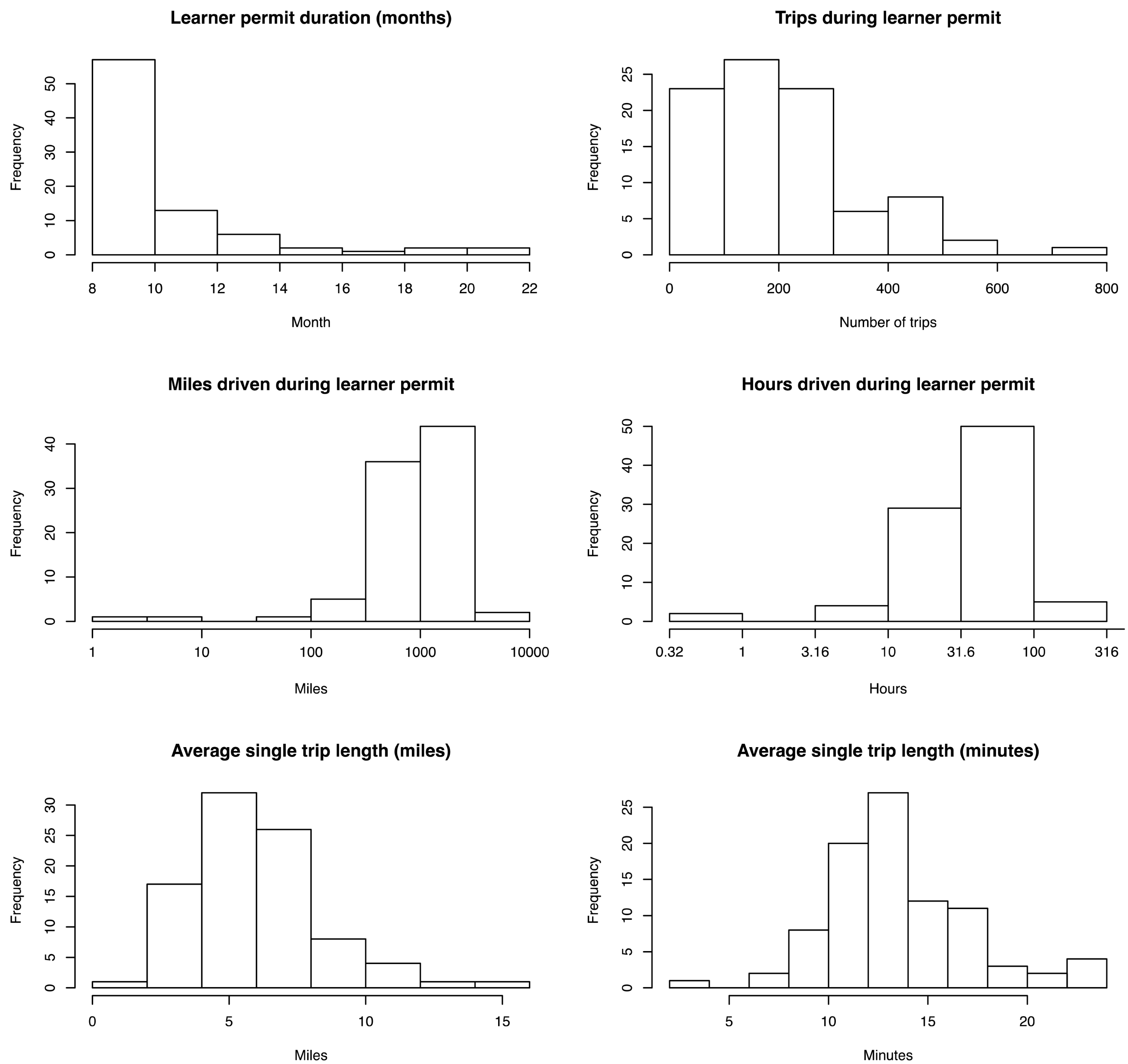

Figure 1. Histograms of Exposure Measures from the Practice Driving Period

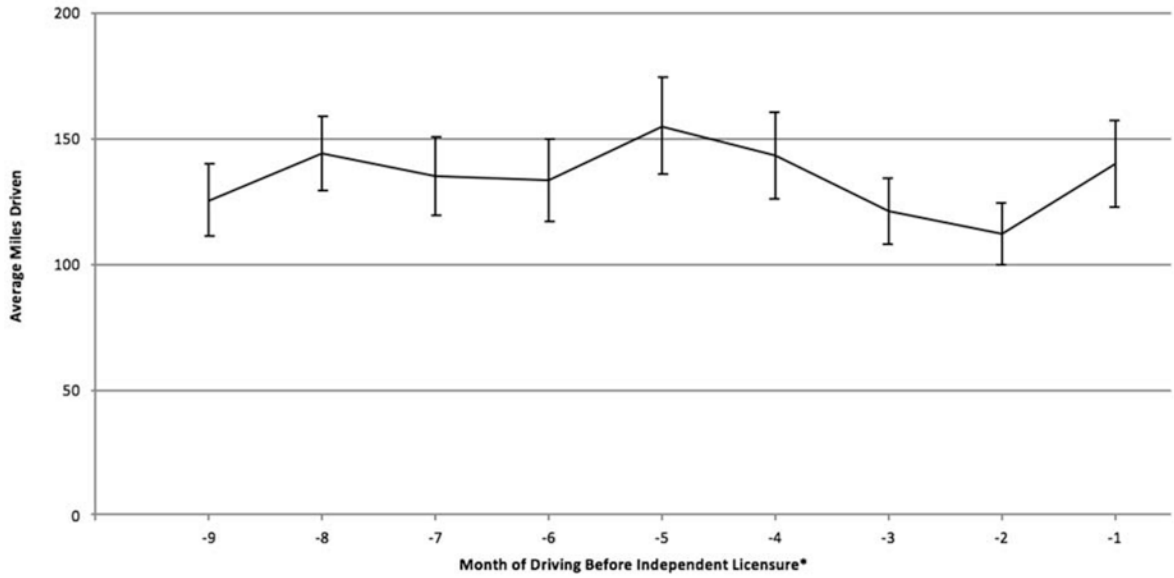

Figure 2. Average number of miles driven by teenagers during the learner license stage (with between-subject standard-error bars)

*Negative months indicate the consecutive 9 months of driving required during the learner license stage. All participants held their learner permit for a minimum of 9 months.

Table 1

Mean and Distribution of Driving Exposure Measures During the Learner Permit Period (n=90)

Driving Exposure Measure	Mean	Standard Deviation	25th Percentile	50th Percentile	75th Percentile
Total Months	10.64	2.83	9.13	9.20	10.83
Total Trips	207.62	141.13	97.00	192.00	275.00
Total Miles	1219.06	920.19	502.39	104 000	1637.59
Total Miles at Night	263.38	300.42	61.78	159.95	332.77
Total Miles in Wet Conditions	127.52	112.72	46.59	92.18	170.57
Total Hours	46.56	32.28	24.39	40.39	61.58
Total Hours at Night	10.07	10.18	3.34	6.97	13.49
Total Hours in Wet Conditions	5.15	4.16	2.47	4.10	7.10
Average Single Trip (miles)	5.89	2.45	4.15	5.63	7.32
Average Single Trip (minutes)	13.68	3.61	11.49	13.37	15.86

Table 2

Prevalence and Likelihood of Occurrence of Driving Instruction During the First and Last Ten Hours of Practice Driving

Topic	First 10 Hours N=90 participants# 9,823 observations			Last 10 hours N=79 participants# 8,523 observations			Odds Ratio (Last 10 Hours versus First 10 Hours)		
	N*	Percentage (SD)^		N*	Percentage (SD)^		Odds Ratio+	95% Confidence Interval	
Any Conversation Present	8,267	84.2	(11.1)	6,428	75.9	(15.5)	**0.56**	**0.52**	**0.61**
Functional Instruction	4,793	49.9	(17.9)	2,475	31.2	(14.3)	**0.42**	**0.39**	**0.45**
Navigation	1,467	14.6	(8.9)	703	9.7	(11.8)	**0.52**	**0.47**	**0.57**
Give Warning/Detect Hazard	979	9.7	(5.8)	384	4.7	(3.8)	**0.44**	**0.39**	**0.50**
Vehicle Handling or Operation	2,503	27.2	(18.4)	1,217	16.3	(13.6)	**0.49**	**0.45**	**0.53**
Remarking on Driving Behavior	1,275	14.4	(13.2)	604	7.2	(4.9)	**0.49**	**0.44**	**0.54**
Question About Driving Task	69	0.9	(2.2)	13	0.2	(0.5)	**0.23**	**0.13**	**0.42**
Rules of the Road	699	7.0	(4.6)	251	3.2	(3.5)	**0.40**	**0.34**	**0.47**
Higher Order Instruction	1,199	13.3	(12.0)	1,012	12.5	(6.6)	0.99	0.90	1.09
Navigation	86	0.9	(1.1)	140	1.7	(1.4)	**1.92**	**1.46**	**2.53**
Give Warning/Detect Hazard	291	4.0	(10.7)	104	1.4	(1.7)	**0.41**	**0.32**	**0.51**
Vehicle Handling or Operation	387	4.0	(3.5)	202	2.6	(2.3)	**0.62**	**0.52**	**0.74**
Remarking on Driving Behavior	388	5.1	(10.9)	292	3.7	(2.9)	0.90	0.76	1.05
Question About Driving Task	18	0.2	(0.4)	6	0.1	(0.3)	**0.38**	**0.15**	**0.98**
Rules of the Road	165	1.7	(1.6)	106	1.4	(1.4)	**0.73**	**0.57**	**0.94**

*Total number of video segments where instruction was observed.. The sum of subcategories exceeds the total N as multiple topics/forms of instruction occur in each segment

^Estimated using total unique instances of conversation or instruction. May exceed 100% as multiple topics and types of instruction occur in each video segment, SD = Standard Deviation

+Significant values in bold

#Due to participant withdrawal and limited practice by several teens, data for the final ten hours of practice driving were available for 79 participants

Table 3

Prevalence and Likelihood of Occurrence of Conversation and Driving Instruction During Normal Driving Segments and Elevated G-Force Events

Topic	Baseline N = 90 participants# 18,346 observations			Events N = 79# 500 observations			Odds Ratio (Event versus Baseline)		
	N*	Percentage (St.Dev.) ^		N*	Percentage (St.Dev.) ^		Odds Ratio+	95% Confidence Interval	
Any Conversation Present	14,695	81.1	(12.2)	436	88.8	(20.5)	**1.63**	**1.23**	**2.15**
Functional Driving Instruction *	7,268	42.1	(16.7)	331	77.1	(25.1)	**3.35**	**2.73**	**4.10**
Navigation	2,170	13.0	(11.7)	70	14.8	(23.4)	1.19	0.91	1.55
Give Warning/Detect Hazard	1,363	7.5	(4.6)	93	25.1	(31.7)	**3.16**	**2.47**	**4.05**
Vehicle Handling or Operation	3,720	22.5	(16.6)	225	55.2	(32.3)	**3.70**	**3.03**	**4.50**
Remarking on Driving Behavior	1,879	10.7	(7.8)	156	39.3	(35.1)	**4.56**	**3.69**	**5.62**
Question About Driving Task	82	0.6	(2.1)	15	4.7	(14.9)	**7.16**	**4.01**	**12.76**
Rules of the Road	950	5.3	(3.4)	44	12.2	(22.8)	**1.92**	**1.38**	**2.68**
Higher Order Driving Instruction *	2,221	13.0	(11.7)	124	44.2	(27.8)	**3.16**	**2.51**	**3.98**
Navigation	226	1.2	(1.0)	8	2.3	(8.0)	1.46	0.70	3.05
Give Warning/Detect Hazard	395	2.1	(1.6)	42	16.6	(27.7)	**6.27**	**4.16**	**9.45**
Vehicle Handling or Operation	589	3.3	(2.6)	59	24.6	(29.1)	**5.40**	**3.76**	**7.78**
Remarking on Driving Behavior	680	3.8	(2.6)	50	19.8	(26.5)	**4.98**	**3.63**	**6.82**
Question About Driving Task	24	0.1	(0.3)	3	2.8	(15.0)	**3.93**	**2.82**	**5.46**
Rules of the Road	271	1.5	(1.2)	32	12.9	(24.9)	**5.71**	**1.64**	**19.93**

*Total number of video segments where instruction was observed. The sum of subcategories exceeds the total N as multiple topics/forms of instruction occur in each segment

^Estimated using unique instances of conversation or instruction. May exceed 100% as multiple topics/forms of instruction occur in each video segment, SD = Standard Deviation

+Significant values in bold

#Data were available from N=90 participants for the first ten hours of practice driving and N=79 participants for the final ten hours of practice driving. Data from the random selection of highly elevated g-force events were from 79 participants

Table 4

Prevalence and Likelihood of Occurrence of Driving Errors and Secondary Task Engagement During the First and Last Ten Hours of Practice Driving

Driving Errors	**First 10 Hours N=90 participants# 9,823 observations**			**Last 10 hours N=79 participants# 8,523 observations**			**Odds Ratio (Last 10 Hours versus First 10 Hours)**		
	N	**Prevalence (St. Dev.)^**		**N**	**Prevalence (St. Dev.)^**		**Odds Ratio+**	**95% Confidence Interval**	
Total Driving Errors	1,13 8	13.4	(19.4)	786	8.8	(13.0)	**0.76**	**0.68**	**0.84**
Performance Errors	638	8.4	(19.3)	605	6.8	(11.3)	1.10	0.97	1.25
Lane management	400	4.8	(7.4)	578	6.4	(11.3)	**1.72**	**1.49**	**1.98**
Loss of vehicle control	3	0.0	(0.2)	0		-	-	-	-
Improper turning	69	1.3	(6.3)	4	0.1	(0.2)	**0.07**	**0.02**	**0.18**
Hard braking	45	0.5	(0.8)	11	0.1	(0.4)	**0.28**	**0.15**	**0.56**
Improper vehicle operation	121	1.8	(6.6)	12	0.1	(0.4)	**0.11**	**0.06**	**0.21**
Decision Errors	352	3.5	(2.9)	124	1.4	(2.4)	**0.40**	**0.32**	**0.49**
Too fast for conditions	172	1.8	(2.1)	78	0.92	1.72	**0.52**	**0.39**	**0.68**
Too slow for conditions	107	1.0	(1.8)	14	0.17	0.65	**0.15**	**0.08**	**0.26**
Gap acceptance	31	0.3	(0.6)	13	0.15	0.46	**0.50**	**0.26**	**0.97**
Failing to stop/yield	42	0.4	(0.6)	19	0.21	0.65	**0.52**	**0.30**	**0.90**
Recognition Errors	90	0.9	(1.2)	34	0.4	(0.9)	**0.43**	**0.29**	**0.65**
Hazard Detection	32	0.3	(0.6)	9	0.1	(0.3)	**0.32**	**0.15**	**0.69**
Inattention/dist raction	58	0.6	(1.2)	25	0.3	(0.8)	**0.50**	**0.31**	**0.81**
Other	58	0.6	(1.0)	23	0.2	(0.8)	**0.44**	**0.27**	**0.73**
Driving Errors by Road Type									
Parking Lot	157	14.2	(21.8)	57	4.7	(7.8)	**0.39**	**0.28**	**0.55**
Residential Rural	465	10.5	(8.0)	277	6.9	(10.2)	**0.65**	**0.55**	**0.77**
Suburban Commercial	194	10.1	(9.0)	85	5.2	(8.6)	**0.50**	**0.38**	**0.66**
Urban Commercial	70	9.4	(16.3)	58	4.4	(9.4)	**0.55**	**0.37**	**0.83**
Highway	252	9.5	(12.7)	309	9.8	(16.3)	1.21	0.99	1.48
High Risk Secondary Tasks	554	5.8	(4.6)	878	9.9	(7.6)	**1.93**	**1.72**	**2.17**

*Total number of video segments where each error was observed

^Estimated using total unique instances where errors were observed. Multiple errors types may occur in each video segment, SD = Standard Deviation

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[+]Significant values in bold

[#]Due to participant withdrawal and limited practice by several teens, data for the final ten hours of practice driving were available for 79 participants